Hans Christian Oersted—Scientist, Humanist and Teacher [1]

J. Rud Nielsen
Department of Physics, University of Oklahoma, Norman, Oklahoma

OERSTED is known to the world as the discoverer of electromagnetism. In Denmark he is remembered with equal gratitude as a great teacher and exponent of physical science, and as the founder of the Royal Technical College and other institutions which have contributed to the enlightenment and welfare of the country. His greatness, not least as an educator, depended on the fact that his interests extended over the entire range of human culture. He was a humanist as well as a scientist. "None of our scientists," he was once told, "regard art, science and men from such a comprehensive point of view as you." The wide scope of Oersted's writings makes them valuable as source material for anyone who wishes to familiarize himself with the status of physical science and philosophy in the early part of the nineteenth century.

Education

Hans Christian Oersted was born in 1777 at Rudkøbing in one of the smaller Danish islands. His early education was rather irregular. The wife of an old German wigmaker taught him to read and to write; the wigmaker taught him German and as much arithmetic as he knew himself, namely to add and to subtract. Multiplication he learned from an older boy and division, from the parson. A former university student taught him Latin and other subjects, and the town judge gave him and a one-year younger brother lessons in French and English. In addition, the brothers "seized with avidity all other means of gaining knowledge. . . ."[2] From his eleventh year Hans Christian helped in his father's pharmacy; and the laboratory work together with the reading of chemical books early aroused his interest in natural science.

In 1794 the two brothers went to Copenhagen to prepare for admission to the University, which they entered the following year. Both of them soon became ardent exponents of Kant's new critical philosophy. Hans Christian heard lectures on mathematics and physical science; his brother took up law and later became a famous jurist. They led a studious life and lived together in *Elers Collegium*, in the very rooms in which the writer of the present article lived more than a century later. The poet Oehlenschläger described them as follows:

> As in a dim monastic cell the Oersteds sat here, grave, silent, at their studies. . . . To all their fellow students they shone resplendent like the Dioscuri, and even ripe scholars soon noticed what was in them.

In 1797 Oersted graduated as a pharmacist with high honors. The previous year he had won the university gold medal for an essay on esthetics. He was awarded the same prize, in 1798, for a medical paper on the origin and function of the amniotic fluid. In addition to the two prize essays, he published in 1798 two "Chemical Letters." In the opening paragraph of the first of these, he wrote:

> I promised . . . to give you an account in letters of the systematic parts of chemistry. . . . I keep my promise with pleasure, both for your sake and for that of science, which you know I find so much pleasure in communicating to others.

This desire to write for the general public stayed with him all his life, and there were few years when he did not write one or more popular papers. In the same year, Oersted wrote the first of many essay book reviews. These were

[1] This article is based largely on Oersted's collected scientific papers, edited by Dr. Kirstine Meyer, née Bjerrum, and published in 1920 by the Royal Danish Academy of Sciences and Letters, under the title *H. C. Ørsted, Naturvidenskabelige Skrifter*, ved Kirstine Meyer f. Bjerrum (Andr. Fred. Høst & Søn, Copenhagen). This work, consisting of three large volumes, contains also two essays by Doctor Meyer. The first of these, entitled "The Scientific Life and Works of H. C. Ørsted," is printed in English; the other, dealing with Oersted's varied activities in the Danish commonwealth, is in Danish. The first two volumes contain 61 scientific papers of which only nine are in Danish. The second volume contains, in addition, 66 papers (in Danish) read before the Royal Danish Academy of Sciences and Letters. In the third volume are reprinted some 50 popular papers on physical science (in Danish). The work does not include Oersted's textbooks, nor his philosophic and poetic works. The writer is indebted to the Danish Academy of Sciences and to Professor Martin Knudsen of the University of Copenhagen for kindly placing this and other material at his disposal.

[2] Since most of the sources quoted are Danish, no detailed references are given. All of the quotations are from the writings of Oersted or his contemporaries. The writer of this article is responsible for the translation of most of them.

rather lengthy and, as he explained, written "in such manner that they have a content of their own, i.e., that they may be read with interest and profit independently of the books which they review and appraise."

In 1798, a new journal was started in Copenhagen for the purpose of promoting the Kantian philosophy, and Oersted became a member of the editorial staff. He contributed a paper on Kant's *Metaphysical Foundations of Natural Science*. This was elaborated into a dissertation, written in Latin, for which, in 1799, he won the degree of Doctor of Philosophy. The thorough study of the critical philosophy gave Oersted a sharp sense for systematic thinking and formed an excellent background for his later scientific work, although it made him an opponent of the atomic theory for the greater part of his life. In these early writings Oersted displayed a great enthusiasm for physical science and a remarkable power to express himself in clear and elegant language.

First Teaching Experience and Physical Research

It was now time to look for a position, and Oersted had his heart set on an academic career. The prospects, however, were far from good. In fact, the state of physics at the University of Copenhagen was a sorry one in those days. Physics had been a subject in its own right since the beginning of the sixteenth century. However, when Pietism flourished in the early part of the eighteenth century, the chair of physics was discontinued to make possible an expansion of the divinity school. Physics was taught by the professors of mathematics or medicine. In 1800, the medical professor who had taught physics and chemistry died, and Oersted, who was then substituting as manager of a well-known pharmacy, applied for that part of the position which concerned physical science. The patron of the University, the Duke of Augustenborg, and several of the older professors were opposed to Oersted because of his advocacy of the new-fangled Kantian system; but the pressure of his many friends was so strong that he was finally appointed "adjunct," without salary, with the duty of lecturing two hours a week to the pharmaceutical students. This was hardly an enviable position, but Oersted accepted it with enthusiasm and apparently added a lecture and a laboratory for graduates. Laboratories were then unknown in Denmark, as in most other places, and Oersted could arrange the laboratory only by using the facilities and space of the pharmacy which he managed.

In the year 1800 Volta constructed his galvanic pile, and with its aid Nicholson and Carlisle discovered the electrolytic decomposition of water. This stimulated Oersted's first physical research. He constructed a small battery of novel design and invented a gas voltameter, by means of

Oersted as a young man. [From a copper-print made by Crétien, Paris, 1803.]

which, he said, "we shall be able to measure galvanism even more accurately than electricity." He also discovered that "syrup of violets" is stained green by the negative and red by the positive electrode, and found that the colors disappear on shaking. He did not follow up these observations, either for lack of time or because he did not fully recognize their importance.

Travel Abroad

In 1801 Oersted, then nearly 24 years old, received a traveling fellowship and set out on a trip to Germany and France which lasted two and a half years. Although not all the influences to which he was subjected on this journey were of equal value, the trip was of great importance for his later scientific work. He traveled by wagon from town to town, visiting universities, factories, mines and museums. Wherever there was an opportunity he attended lectures, worked in laboratories, or "galvanized" with the small battery that he carried with him. In Berlin he associated mainly with the philosophers, Fichte, A. W. Schlegel and his brother Friedrich, and made a thorough study of Schelling's philosophy of nature. Although he was not blind to the dangers of the romantic movement, which he recognized more clearly later, he was deeply influenced by it. In Oberweimar and, later, in Jena, Oersted visited Ritter who shortly afterwards discovered the electrolytic polarization. Ritter and Oersted became close friends and performed a number of galvanic experiments together. Ritter was a clever experimenter and the creator of several rather fantastic theories that appealed to Oersted at the time. During his first stay with Ritter, Oersted became acquainted with a book obscurely written in Latin by the Hungarian chemist, Winterl. Its leading idea, namely, that all the forces of nature arise from the same fundamental causes, appealed greatly to Ritter and Oersted. They succeeded in showing, to their own satisfaction, the connection between electricity and heat, light, and chemical effects; but with magnetism they had difficulty, although the researches of Coulomb pointed to a fundamental similarity between electricity and magnetism. Oersted decided to adapt Winterl's work for German readers. His book was published in 1803 under the title *Materialien zu einer Chemie des neunzehnten Jahrhunderts*. It was not well received, especially outside Germany where the romantic philosophy of nature had not penetrated; and its publication caused Oersted some embarrassment after his return to Denmark.

In 1802 Oersted went to Paris, where he stayed more than a year. Although he missed the philosophic atmosphere, he gradually learned to appreciate the high development that physical science had reached there. He published two papers on Ritter's galvanic discoveries and did his best to secure for Ritter a large prize offered by Napoleon. He attended lectures and made detailed notes, not only of their contents, but also on their form:

> I learn here daily much about the art of lecturing: from Charles, the way lectures should be delivered; from Vauquelin, how they should not be delivered. . . . I realize how much I have lacked of this art, or rather that I have not known it at all; but when I have completed the training I have now begun I hope to return the wiser. . . .

About Cuvier's lectures he writes:

> These belong to the most interesting of those I have had opportunity to attend. It is the philosophy of natural history that he is here occupied with. . . . It is the spirit of science that he depicts. . . . As to his delivery, it is fluent and beautiful without being embellished with the empty rhetorical phrases of the French.

About Berthollet he writes:

> He speaks with difficulty and hence somewhat slowly; but this very manner fits well the profound ideas that he teaches.

Oersted was enthusiastic about the *École Polytechnique*, especially about the student laboratories:

> The mere dry lectures such as they are given in Berlin without the art of experimentation do not please me; for, after all, all scientific advances must start from experimentation.

Teaching and Textbook Writing

In January, 1804, Oersted returned to Denmark. The enthusiasm for the romantic philosophy of nature revealed in his writings had not pleased the University administration, so he had no hope of obtaining a salaried position. An influential friend advised him to go into applied chemistry, but he replied that while he would be glad to lecture occasionally on technical problems, he was primarily interested in pure chemistry and physics, and rather than seek financial success he would live in accordance with his ideas. After obtaining charge of a collection of physical and chemical instruments belonging to the king, he issued a printed invitation to private lectures on physics and chemistry for which he charged admission. These lectures were a great

success, and the attendance increased from year to year. In 1805 he writes in a letter:

> My lectures on chemistry are so strongly attended this year that not all could find room. These lectures are also attended by five or six ladies. You will readily imagine that I make no change in my lectures for their sake.

In another letter, he says:

> These lectures are attended by women as well as by men, although I have only five women. As an introduction to these lectures, I gave in the first three hours a survey of the difference between the older and the newer status of physics. These three lectures were open to the public. My lecture room was far too small to hold all who desired to come, and I won much applause. . . .

A student who attended Oersted's lectures a few years later described his way of lecturing in the following words:

> He usually began very quietly with a few observations and instructive remarks; sometimes also with derivations and definitions of particular terms, whereby he wished to make sure that he would be understood when he proceeded further; once in a while he would also pause to discuss the translation of chemical or physical terms into the Danish language. He then pursued a definite series of phenomena and ideas which were closely related to each other and to the definitions first given. In the beginning his lecture was distinguished almost solely by sharp reasoning, but little by little the separate objects united into larger groups and these in turn joined into a greater unity which he presented vividly to our imagination. Thus his speech became ever mightier, like a stream which grows and is joined by many tributaries, and finally it acted with such a power that at least the younger ones, who were not yet bound by preconceived notions and were susceptible to the new and unusual in his delivery, could with difficulty resist him.

The success of these private lecture courses could not fail to impress the University administration, and in 1806 Oersted was appointed *professor extraordinarius* in physics with the duty to examine candidates in philosophy and to teach physics and chemistry to medical and pharmaceutical students. Although the salary was miserable, Oersted was happy: "I obtain hereby the privilege of being able to found a school of physics in Denmark, for which I hope to find some talented persons among the many young students I shall now have."

With Oersted's appointment, physics was again recognized as a science in its own right rather than merely as a service discipline for medicine and pharmacy. However, only after a long struggle did this recognition become more than a gesture. Oersted worked out detailed proposals for a reform of the study of physics, but they were shelved by the administration. In one of these plans he mentions that on a trip abroad he had made a study of the influence which the experimental sciences had upon a country's welfare. He continues:

> The first question I asked myself was if the chemists and physicists really are right when they claim that their science has such an important influence upon the welfare of the state and if the conviction which I had myself in this regard was based on sufficiently solid reasons. I found that this question must really be answered with a "Yes!" In a country where the scientific knowledge has really penetrated there is soon formed among all educated people a clear idea of what science is able to do and what must be left to practice. . . . But the most important advantage of the diffusion of chemistry and physics among all classes is this, that the practicians acquire theory. . . . If the value of the experimental sciences is considered solely from the point of view of national economics, it may be said that the state needs theorists only to teach the practical people those parts of the theory which are most important to them and to enrich science with new theories which always, sooner or later, will be useful to the practicians.

With his great ability as a writer and his interest in teaching, it was natural that Oersted should write several textbooks. His largest work, *The Science of the General Laws of Nature, Part I*, which appeared in 1809, dealt with the mechanics of solids and fluids and with sound. A second part was to treat "chemical physics"—heat, electricity, magnetism and optics, in addition to what we now call chemistry; but it was never completed, although several of the subjects were treated in separate books. *Part I* appeared in several editions and was used in Denmark for more than fifty years. According to the preface, it was written in such a manner that it could be used both by beginners and by advanced students:

> It is my wish and in part my hope that the students who once, through this work and through my lectures, have acquired a good background in physics should continue this study during the rest of their lives and use this book, with the aid of which they have made their first step in science, as a companion on their further path. . . . I readily admit that I have not

labored for those who merely wish to obtain the knowledge necessary to earn their daily bread in some position.

The introductory chapter, entitled "General Remarks about Science," although now naturally out of date, is vastly superior to the corresponding chapter in most present-day textbooks. In this introduction, as in many other places, Oersted emphasizes the importance of studying the history of science. "By such a study . . . one gains an insight into the development of the whole human mind. . . ." An interesting feature of this book and of several later writings is Oersted's attempt to coin short and natural Danish words to take the place of awkward foreign terms. Many of his new words, such as "ilt" for oxygen (from "ild" = fire) and "brint" for hydrogen (from "brænde" = burn), have become a permanent part of the Danish language. In the preface, Oersted promised to publish an annual supplement in order to bring the book up to date. Time did not permit him to keep this promise. Instead, he delivered, for the rest of his life, a monthly lecture devoted to recent advances in physics and chemistry.

Oersted also wrote papers on the teaching of science with titles such as "On the Manner in Which a Textbook of Physics Should be Written," and "The Briefest Way of Presenting the Theory of Electricity through a Series of Experiments." In this connection it may be mentioned that he, some years later, invented a peculiar grading system (with the scale, 8, 7, 5, 1, −7, −23) which is used in Denmark to this day.

In 1815, the king presented his collection of physical instruments to the University, and increased appropriations were made available for experimental work. Oersted spared no efforts to add to this collection and to find the best available quarters for it. It was of the utmost importance both for his research and for his teaching. Once he wrote in a letter: "I have now beautiful instruments and can fortunately make any experiments whatsoever." In connection with the problem of housing the instrument collection, Oersted succeeded in establishing the first chemical laboratory at the University of Copenhagen. At first, this laboratory consisted merely of a kitchen, but it had the grand name of Royal Chemical Laboratory. A few years later,

Oersted in 1822. On the table stands the compass needle; in his hand is a metal disk on which an acoustic figure is formed; in the background may be seen an early form of his piezometer and also a large galvanic battery. [From a painting by Eckersberg.]

Oersted's pupil, W. C. Zeise, the discoverer of mercaptan and xanthogenic acid, became the first Professor of Chemistry. Oersted's growing reputation as a scientist and his remarkable ability as a lecturer gradually broke down the disfavor with which he was looked upon by the administration and, in 1817, he was made *professor ordinarius* and member of the governing board of the university.

Scientific Work

Oersted's teaching load was heavy and for many years economic difficulties forced him to add to his income by extra work. At times he was discouraged, but somehow he managed to continue his experimental and theoretical researches. There are indications that his teaching gave him stimulation for scientific work. Thus he begins one paper with the words: "My physical researches go in part parallel with my lectures." On the other hand, he began many very promising investigations which his other duties prevented him from carrying to completion.

In 1807 he finished an extensive and important investigation of acoustic figures to which he was led by the hope of finding electrical effects accompanying the oscillations. The introduction to his paper contains this interesting reference to Chladni:

> It follows from the infinity of nature that no observer can discover all that is in an experiment. To understand an experiment quite completely would be the same as finding the key to all of nature. Hence one cannot reproach the ingenious discoverer of the acoustic figures if he has not observed all that really lies in his experiments.

The last part of the paper consists of philosophic speculations on the "profound incomprehensible reason of nature which speaks to us through the flow of music." These ideas were later elaborated in a paper, "On the Cause of the Pleasure Produced by Music."

In 1812 Oersted went abroad again, spending more than a year, mainly in Berlin and Paris, It is interesting to note that he is now rather critical toward the German romantic philosophers about whom he was so enthusiastic in his youth:

> It is also my firm conviction . . . that a great fundamental unity permeates all nature, but just when we have become convinced of this it is doubly necessary that we turn our attention to the world of the manifold where this truth will find its only corroboration. If we do not, unity itself becomes a barren and empty thought leading to no true insight.

On this trip he completed a theoretical work on chemistry which was first published in German and shortly afterwards adapted for French readers under the title, *Recherches sur l'identité des forces électriques et chymiques*. The main conclusion of this book is that all chemical affinities, as well as heat and light, are produced by the positive and negative electricities. The book was well received but, because of its philosophic form and the qualitative nature of its many ingenious observations, it is difficult to ascertain what influence it had. Oersted is still true to his Kantian convictions in opposing the atomistic theory. An interesting feature of the book is the development of an electrical wave theory of light which was elaborated in later papers.

Oersted's researches in the next decade covered a wide range of fields. Volta, and later Simons, had obtained results that seemed to disprove Coulomb's inverse square law for electrostatic forces; so Oersted repeated Coulomb's experiment. He verified the inverse square law for moderate distances but found deviations from this law for very small and very great distances. However, he apparently was not quite convinced about their reality. In the years 1818 and 1819, he investigated the minerals of the island of Bornholm and, in 1820, he discovered the alkaloid piperine.

The Discovery of Electromagnetism

The belief in a connection between electricity and magnetism had taken a firm hold of Oersted's mind during the time of his association with Ritter. It was nourished by his study of the romantic philosophy of nature, although this philosophy otherwise retarded rather than furthered his scientific development. In 1808, Oersted had proposed the problem of the relation between electricity and magnetism for the prize essay of the Danish Academy. In his *Researches on the Identity of Electrical and Chemical Forces*, he had attempted to show that the magnetic effects are produced by electricity; but, as he later put it himself, "he was well aware that nothing in the whole work was less satisfactory than the reasons he alleged for this." In 1817, he constructed, together with Esmarch, a large galvanic battery of small internal resistance with which he made a number of electrolytic experiments. No remarkable results were forthcoming until in April, 1820, when, during an evening lecture, he discovered the effect of an electric current upon a magnetic needle. In the *Edinburgh Encyclopedia*, Volume 18 (1830), Oersted gives the following account of his discovery:

> Electromagnetism itself was discovered in the year 1820 by Professor Hans Christian Oersted of the University of Copenhagen. . . . In the winter of 1819–20, he delivered a course of lectures upon electricity, galvanism and magnetism before an audience that had been previously acquainted with the principles of natural philosophy. In composing the lecture, in which he was to treat of the analogy between magnetism and electricity, he conjectured that if it were possible to produce any magnetical effect by electricity, this could not be in the direction of the current, since this had been so often tried in vain, but that it must be produced by a lateral action. This was strictly connected with his other ideas, for he did not consider the transmission of electricity through a conductor as an uniform stream but as a succession of

interruptions and re-establishments of equilibrium in such a manner that the electrical powers in the current were not in quiet equilibrium but in a state of continual conflict. As the luminous and heating effect of the electrical current goes out in all directions from a conductor which transmits a great quantity of electricity, so he thought it possible that the magnetical effect could likewise eradiate. The observations, above recorded, of magnetical effects produced by lightning in steel-needles not immediately struck confirmed him in his opinion. He was nevertheless far from expecting a great magnetical effect of the galvanical pile; and still he supposed that a power sufficient to make the conducting wire glowing might be required. The plan of the first experiment was to make the current of a little galvanic trough apparatus, commonly used in his lectures, pass through a very thin platina wire which was placed over a compass covered with glass. The preparations for the experiments were made but, some accident having hindered him from trying it before the lecture, he intended to defer it to another opportunity; yet, during the lecture, the probability of its success appeared stronger, so that he made the first experiment in the presence of the audience. The magnetical needle, though included in a box, was disturbed; but as the effect was very feeble and must, before its law was discovered, seem very irregular, the experiment made no strong impression on the audience. It may appear strange that the discoverer made no further experiments upon the subject during three months; he himself finds it difficult enough to conceive it; but the extreme feebleness and seeming confusion of the phenomena in the first experiment, the remembrance of the numerous errors committed upon this subject by earlier philosophers, and particularly by his friend Ritter, [and] the claim [i.e., demand that] such a matter has to be treated with earnest attention may have determined him to delay his researches to a more convenient time. In the month of July, 1820, he again resumed the experiment, making use of a much more considerable galvanical apparatus. The success was now evident, yet the effects were still feeble in the first repetitions of the experiment because he employed only very thin wires, supposing that the magnetical effect would not take place when heat and light were not produced by the galvanical current; but he soon found that conductors of a greater diameter give much more effect, and he then discovered, by continued experiments during a few days, the fundamental law of electromagnetism, *viz., that the magnetical effect of the electrical current has a circular motion round it.*

On July 21, 1820, Oersted announced his discovery in a paper entitled *Experimenta circa effectum conflictus electrici in acum magneticam*, which was sent to learned societies and scholars in the various European countries. An English translation appeared in Thomson's *Annals of Philosophy* (London, 1820). In this paper, which is rather too brief to be perfectly intelligible, Oersted describes some of his experiments and gives a simple rule for finding the direction of the force upon the magnetic pole. In stating his findings he says that the effect passes through all the various mediums which he placed between the conductor and the magnet, and that the force depends upon the nature of this medium, as well as upon the distance from the conductor and the strength of the battery. He mentions that needles of brass and other materials were unaffected by the "electric conflict," as he calls the current. He concludes that:

> It is sufficiently evident from the preceding facts that the electric conflict is not confined to the conductor but [is] dispersed pretty widely in the circumjacent space. From the preceding facts we may likewise collect that this conflict performs circles. . . . This I think will contribute very much to illustrate the phenomena to which the appellation of polarization of light has been given.

Immediately afterwards Oersted published another paper which appeared in the July issue of Schweigger's *Journal für Chemie und Physik* and, in English translation, in Thomson's *Annals of Philosophy*. In this paper he shows that "the magnetic effects do not seem to depend upon the intensity of the electricity but solely on its quantity"; hence, a greater effect is produced by a single large cell than by a large battery of small cells. He also shows that a suspended circuit behaves like a magnet.

On the basis of notes found after Oersted's death, Doctor Kirstine Meyer has succeeded in reconstructing in considerable detail the series of experiments which he carried out in July, 1820. Her findings corroborate Oersted's own account.

The importance of Oersted's discovery was immediately recognized. Ampère wrote: "M. Oersted . . . has forever attached his name to a new epoch." Schweigger expressed the same opinion by beginning a new series of his journal. Faraday wrote of Oersted in 1821,

> . . . his constancy in the pursuit of his subject, both by reasoning and experiment, was well awarded in the winter of 1819 by the discovery of a fact of which not a single person besides himself had the slightest suspicion, but which, when once known, instantly drew the attention of all those who were at all able to appreciate its importance and value.

On a later occasion, he said of the discovery, "It burst open the gate for a domain in science, dark until then, and filled it with a flood of light."

In view of these clear statements of appreciation, it is strange that the stories should have developed that Oersted's discovery was purely accidental and incomplete, that the deflection of the needle was first observed by a janitor, that the discovery was not made by Oersted at all but by Schweigger, and so on. Doctor Meyer has shown that the chief errors, although elaborated by later German writers, originated in an article by the editor of *Annalen der Physik*, Gilbert, who had been unable to understand fully Oersted's Latin paper.

The rapidity with which new discoveries followed Oersted's is well known. Before the end of the year, Ampère had discovered the mutual action of currents, and Arago had constructed the first electromagnet. In 1821 Schweigger invented the "multiplier" or galvanometer and, with its help, Seebeck discovered thermoelectricity. This phenomenon made possible the use of constant electromotive forces and thus led to Ohm's discovery in 1824. An essential part of these advances was the clarification and quantitative definition of such concepts as current, potential difference and electromotive force.

It is symbolic of the great practical importance of Oersted's discovery that the headquarters of the Copenhagen Telephone Company now covers the very spot where he discovered electromagnetism.

Travel and Further Scientific Work

In 1822 Oersted set out on a trip to Germany, France and England, which lasted for nearly a year. Wherever he went, he was honored for his great discovery, for which he had already been awarded the Copley medal by the Royal Society of London and the gold medal of the French Academy. It is again interesting to note the change in his evaluation of the German and the French scientists. He writes:

> In poetry and philosophy I have not noticed that any new shining light has arisen in Germany in recent years. Nor does experimental science fare very well. Berlin has its excellent men in this branch of learning: Seebeck, Erman, Mitscherlich, Heinrich Rose, but from Berlin to Munich, on a journey of about 360 miles during which I have passed through three university towns, I have not found one fairly reliable chemist or experimental physicist. . . . But I found much that was instructive with Fraunhofer at Munich, so that I was able to occupy myself with benefit there for about a fortnight.

From Paris he writes:

> . . . the acquaintances I have made grow every day more cordial and intimate; the benefit I can derive scientifically is thus all the greater. Chevreul, Biot, Fresnel and Pouillet are the men I meet particularly often. . . . Comprehensive science and not only skill in a single branch is now their watchword. . . . If in Germany I am often tempted to protest against the Philosophy of Nature when I see how it is misapplied, in France I feel so much the more called upon to defend it, or rather I feel a fundamental difference in scientific thought which I should not have imagined to be so great if I had not so often felt its vital presence. Still, I am far from falling out with the French on account of this dissimilarity. I now know better than before to appreciate their merit and am therefore on better terms with them.

He had long discussions with Ampère but remained skeptical about the value of the latter's theory. Shortly after his arrival in Paris he gave a report of Seebeck's discovery and with Fourier, as well as alone, made experiments on the new phenomenon for which he proposed the name *thermoelectricity*. With Arago, Oersted discussed the possible connection between light and electromagnetism. In London, Oersted associated especially with Davy, Herschel and Faraday. He also met Wheatstone, who was then a young instrument maker. Oersted performed a number of experiments together with Wheatstone and introduced him to the English scientists.

The most important researches made by Oersted after his discovery of electromagnetism are undoubtedly his preparation of aluminum chloride and metallic aluminum, in 1825, and his extensive series of measurements of the compressibilities of liquids and gases. Since Oersted did not find time to describe his preparation of aluminum in complete form, his name usually is not associated with this achievement. However, a posthumous study of his notes has shown that his claim was well founded. The stimulation to his researches on compressibility came apparently from writing a textbook. These investigations, published in some 20 papers between 1817 and 1845, reveal him as a competent designer of apparatus and a careful and critical experi-

menter. His piezometer and the methods of measurements which he developed were of basic importance for the work of Despretz, Dulong and Arago. The great difficulty which Oersted and his contemporaries had in determining the correction required because of the compression of the glass vessel containing the liquid being studied is very instructive; it might well give present-day physics teachers food for thought.

Oersted's mind was very fertile in ideas, and his papers are full of statements which show that he was on the track of important discoveries. For example, he early surmised that the tangent of the angle of galvanometer deflection rather than the deflection itself should be taken as a measure of the current; he all but stated Ohm's law before it was announced by Ohm; he developed ideas of electric and magnetic fields, and anticipated in a vague way the electromagnetic theory of light. In all too many cases he did not carry his ideas to fruition. This was due in part to his reluctance or inability to give his ideas mathematical form, but it was also caused by the enormous range of his interests. However, while this great diversity of interests hindered him at times in imposing upon himself that limitation which is required for the complete solution of a scientific problem, it was an essential factor in his greatness as a teacher.

As Oersted became absorbed in the new educational enterprises described in the following pages, he naturally found less and less time for research. Yet he continued to experiment until the end of his life. His last experimental research, completed some two years before his death, dealt with diamagnetism and contained the important result that dia- and paramagnetic rods align themselves differently in a nonhomogeneous magnetic field.

In connection with Oersted's scientific work, it should be mentioned that he served as secretary of the Royal Danish Academy of Sciences and Letters for 36 years. His election to this post was followed by a period of reform of the Academy of Sciences and of great scientific advances in Denmark. The work took a considerable part of his time and energy. Thus, the annual *Proceedings*, containing abstracts of all the papers read at the weekly meetings, were written entirely by Oersted for 27 years. Oersted himself read 66 papers before the Academy, in addition to a large number of brief contributions. As secretary of the Academy of Sciences, he was instrumental in establishing the Meteorological Institute and the Magnetic Observatory at Copenhagen.

The Founding of the Society for the Diffusion of Physical Science

On his return trip from England, in 1823, Oersted conceived a plan for spreading the knowledge of physical science to a larger part of the population, and within a year he had founded the Society for the Diffusion of Physical Science in Denmark, with a membership of 200. In the printed invitation to join this society he emphasizes the importance that a more widespread knowledge of physics would have for the various crafts and industries, and thus for the economic welfare of the state; but he also points out that "the knowledge of the laws of nature form an essential part of man's whole range of knowledge and hence of his culture. As little as we are accustomed to admit this, it is nevertheless true."

The first activity of the Society was the holding of public lectures in Copenhagen by Oersted and two of his colleagues. Each gave two lectures a week, and the arrangement was such that the major parts of physics and chemistry and their applications were treated in a cycle of two winters. The attendance at Oersted's lectures was around 200. At the same time Oersted began to train several young men in the art of giving popular lectures with demonstrations. In order to get a practice school, Oersted offered to furnish a teacher in physics and chemistry to one of the secondary schools in Copenhagen; and the offer was accepted, although without enthusiasm. After half a year the first lecturer, equipped with a collection of instruments, was sent to Aarhus, the largest city in Jutland. He not only gave popular demonstration lectures but also acted as a technical consultant in much the same way as American county agricultural agents. In addition, he sent the Society reports on the condition of the industries in the province. Shortly afterwards three lecturers were sent to other towns. Since artisans worked long hours in those days, Sunday schools were established for them in several towns. In some cases the lecturer managed to get physics introduced in the local high school

with himself as unpaid teacher. This method of sending lecturers on physics to the provincial towns was continued for a number of years, although it did not work without difficulties, the chief one being that of securing qualified lecturers.

The Society for the Diffusion of Physical Science did much to encourage the introduction of physics into the schools, especially by lending or donating instruments to schools that were willing to adopt physics as a subject. The outcome was that, in 1845, physics became recognized as a regular part of the curriculum of the secondary schools. After the establishment of the engineering college in 1829, the number of popular lectures in Copenhagen was reduced. However, various new activities were taken up, such as the demonstrations of machines, which began in 1837. During the month of April, 1838, the attendance at these exhibitions was 2185. Printed descriptions and brief oral explanations of the steam engine, "the electromagnetic telegraph," "the electromagnetic motion machine," etc., were given; and the devices were shown in operation. Oersted gave much time and thought to the Society for the Diffusion of Physical Science; and the Society, which is still very active, deserves much credit for the high place that physics and chemistry hold in the interests of the Danish people. Since 1902 it has published the journal, *Fysisk Tidsskrift,* which serves a purpose similar to that of *The American Physics Teacher.* Since 1908, the Society has awarded a gold medal, the Oersted medal, accompanied by a cash prize.

Pioneering in Engineering Education

Although most interested in pure science, Oersted often stressed the benefits which would result from a greater application of physics to practical problems, and he early formed plans for an institution of the type now known as an engineering college. In 1827 one of the officers of the Society for the Diffusion of Physical Science sent plans to the government for the establishment of a trade school similar to a German "Gewerbschule." The proposal was turned over to a committee with Oersted as chairman. It reported that, while such a school might be useful, there was a greater need for an institution on a higher level, for "only a rather high degree of thoroughness can lead to a great and sure application of the natural sciences, and this higher insight is not reached without considerable preparation and prolonged study." Oersted, therefore, proposed that a "polytechnic institute" be formed. He worked out detailed plans whereby it was possible, by a moderate addition to the teaching staff and laboratories already available at the University, to establish such a college without great expense. The entrance requirements, he proposed, should be similar to those of the University. While mathematics, physics and chemistry were to be the chief subjects, he held that:

> . . . the teaching at the Polytechnic Institute must always strive to give the students not only the required knowledge but also such a practice in its application that this knowledge is not a dead treasure when they enter practical life. . . . I believe that no one acquires mathematical ability unless he trains himself in the solution of problems and in applying mathematics everywhere. . . . These lectures [in physics] must be accompanied by experimental exercises conducted in such a way that the students acquire competence in all types of physical experiments. . . . In order to bring about a more perfect cooperation between all the teachers, it is important that each teacher should know what doctrines the others teach; not in order to prevent differences of opinion which stimulate rather than harm when teachers have the requisite wisdom, nor to prevent that repetition of the same truths in different lectures which is inevitable in so related subjects, but in order to enable the teachers to have the proper regard to each other and to correct each other's knowledge in a friendly way. . . . The lectures should be based on printed textbooks. However, these need not be Danish but might be German or French.

Oersted insisted that the teachers should have the same status as University professors.

Oersted's proposal was accepted, and the new institution began its work in the fall of 1829 with Oersted as President and Professor of Physics. In addition, the original faculty consisted of a Professor of Mathematics, two Professors of Chemistry, a Professor of Applied Mechanics, and several teachers of lower rank. At the dedication ceremony Oersted delivered an address "On the Cultural Effects of the Application of the Natural Sciences." The number of engineering students was 22, but several of the lectures were attended also by University students. The course was

originally planned to take two years, but soon it was found necessary to increase the time of study.

The building up of the engineering college, then an entirely new type of institution, at a time when the economic conditions in Denmark were very bad was a task that taxed all of Oersted's ability and strength. But he entered upon it with enthusiasm and devotion. He expected a similar devotion from the faculty. In judging the value of a teacher, he would put teaching ability above scientific attainments, a policy for which he was sometimes criticized. He believed in teamwork on the part of the faculty and insisted, for example, that the professors of mathematics have a good knowledge of the subjects to which their students had to apply mathematics. He took a great personal interest in the students and in the apprentices in the shops.

For a number of years, the budget was very inadequate, and the salaries were low. "I have assumed," he said once in connection with the salary problem, "that we all carry this burden because we saw that the Polytechnic Institute would at present be discontinued if we would demand a salary corresponding to our labors." The difficulty of finding laboratory space for the increasing number of students and for research continued for many years. Shortly before his death, his plans for a great expansion of the Polytechnic Institute and for a substantial raise in the salaries were approved by the government; but he did not live to see them carried out.

Another problem which demanded Oersted's attention for many years was how to place the graduates in suitable positions. He had expected that the industries would be anxious to employ such well-trained men but had failed to reckon with the opposition of the guilds to their new competitors. He took up the fight with the guilds with his usual energy, and with considerable success, although the final victory came only in 1849, when a political upheaval gave Denmark a free constitution. Oersted also had to fight for the academic rights of the Polytechnic graduates. After some years they obtained the same status as University graduates, permitting them to hold fellowships and, on certain conditions, to dispute for the doctor's degree.

As the prestige of the Polytechnic Institute grew, the government referred more and more technical problems to it. Oersted himself wrote many important reports which bear witness of the broad understanding and clear vision that characterized his other activities. For example, when a foreign engineer applied for a monopoly on an improved telegraph, Oersted advised "that the construction of electric telegraphs either be undertaken by the government or at least be made a large public enterprise."

The Polytechnic Institute, now called the Royal Technical College, continues to enjoy a high reputation among European engineering schools. Besides the Physical Instrument Collection, it now has an Oersted Museum in which Oersted's instruments, including the famous compass needle, and many of his private possessions may be seen.

Poetic and Philosophic Writings

As previously mentioned, Oersted's first scholarly work was a paper on esthetics, and throughout his life he cultivated poetry and the fine arts. "I philosophize, experiment and write poetry," he once wrote in a letter. In 1836 he published a large poem, *The Airship*, in which he attempted to describe the rich and peaceful life that may be attained through the proper cultivation and application of the natural sciences. He sent a copy to the Swedish chemist, Berzelius, asking him to give it to his wife, and wrote in the accompanying letter: "I know that you do not like that one should thus scatter his strength in several fields; but that much I dare say in my defense that it could not be written except by a physicist." Berzelius replied: "You were, like Davy, born a poet, and your poetic bent has exerted its right in your old age. It is now thirty years since our first acquaintance and I remember, as if it were yesterday, how you then with delightful rapture read to me several of the shorter poetical works of Goethe." In the preface to *The Airship* Oersted wrote: "Amongst other things the sciences would seem able to a great extent to act as a guide to us in the investigation of the nature of the beautiful," an idea which he elaborated in a series of papers on "The Natural Philosophy of the Beautiful."

As Oersted grew old, he turned again to philosophy. However, his long scientific life had given him a sense for reality and a tempered judgment, which he had not always possessed in his youth. Having lived a harmonious and happy

life, he never lost his intellectual enthusiasm and optimism or his strong faith in the value of physical science. "It belongs to my plans as a physicist," he wrote in 1836, "to make it evident in every way that the natural sciences should form an essential part of general culture." Some years later he wrote about his work in the decade following the establishment of the Polytechnic Institute:

> My scientific activity in this period is especially marked by an effort to work for my language and my people through popular papers. I have aimed here both at the better educated and the less educated classes. If I am not mistaken, there are certain influences upon human society which ought to issue from the scientists proper, and it is still my opinion that especially the type of thought which is developed by the cultivation of natural science should be extended to a wider circle. Without doubt, the greatest fault of our present culture is an inclination to settle the most important matters according to certain abstract principles without entering into the true relations of these principles to reality. The extremes to which one thereby is misled, be they political, religious, or metaphysical, are all based upon a lack of sense for the truth and reason which lie in the real. That visionary inanity Natural Science is particularly fitted to counteract. I have attempted to apply the scientific spirit in the treatment of religious, esthetic and philosophic topics. That I am far from having produced the effect which I desired is very clear to me; but that I hereby have sown some seeds among the young people who usually flock to my lectures and conversations I dare believe, and I venture to hope for fruits in the future. . . .

His respect for reality is also revealed in the words:

> Should we not feel ashamed in our innermost soul if we caught ourselves in desiring another truth than the real? . . . Let us honor truth! With it the good is inseparably connected. The full truth carries itself its consolation with it.

Statue of Oersted in the Oersted Park at Copenhagen.

Oersted's conception of the laws of nature is indicated by the following statement:

> The train of ideas through which empirical science comes to realize that the laws of nature are laws of reason is not based on any consideration of the wisdom of these laws . . . but depends upon our seeing that which reason perceives confirmed in nature. It is true that we often come to recognize the agreement of the laws of nature with reason only after finding these laws in experience; but often thought runs ahead of experience, and we find that which is thought verified by nature. Hence, we may say in numerous cases: what reason promises, nature keeps.

The idea of unity is again prominent in Oersted's later philosophic writings:

> The laws of nature in the bodily world are laws of reason, the revelation of one reasonable will; if thus we figure to ourselves the whole bodily world as the continual work of eternal reason, we cannot abide by the consideration of this but are carried on to perceive in our thinking also the same laws of the universe. In other words, spirit and nature are one, viewed under two different aspects. Thus we cease to wonder at their harmony.

About two years before his death Oersted completed a large work, *The Spirit in Nature*, which reached several editions and was translated into a number of languages. In this book he attempts to show that religion, art and philosophy must all be based upon that conception of an order in nature to which we are led by natural science. "The world drawn by the poet, with all its freshness and daring, must after all obey the same laws that our spiritual eye discovers in the real world," he once wrote. Scientific work was to Oersted a sort of religious worship. "God's will can never deviate from the laws of nature for the simple reason that the laws of nature are God's will." He had little use

for the dogmas of the Church and on occasions engaged in public controversy with a bishop. He held that Christ has taught us great truths, but has given us no system.

In order to reach a greater part of the population, he often expressed his thoughts in the form of aphorisms or maxims, such as these:

> It is a common spiritual disease to like a new delusion better than an old truth.
>
> When a philosopher scorns Nature because it puts his concepts to shame, he acts like a child who spanks the object that hurt it.
>
> Logic is a dangerous weapon in the hands of passion.
>
> Be stricter to yourself than to others; your egotism is sure to make up for this lack of fairness.

Personality

Oersted possessed a radiant and harmonious personality. He was an optimist by nature and continued to have throughout his life a strong, almost naïve, faith in science and in his fellowmen. He was happy in his work. He was happily married and was a thoughtful husband and father. A friend once came to visit him in his study and found him busy clearing some things from a table. "My wife," Oersted explained, "is going to send my little boy in here, and I put the things away before he comes because I don't like to forbid him to touch them." His home was an intellectual center in Copenhagen and a gathering place for writers, philosophers and scientists. He had many friends whom he was always ready to help by word and deed. "There is nothing in him which one needs conceal or put into a better light before showing it to the world," wrote C. Hauch in 1852, "hence one may well say of him that he was not only a great scientist and a rare thinker but also that he was a great and rare man."

To Hans Christian Andersen, as well as to Zeise and his other students, Oersted was a fatherly and faithful friend. He was the first to appreciate the merits of Andersen's fairy tales and was always ready to console and encourage the poet. Andersen wrote:

> I always returned so clear in thought and rich in mind from the lovable and glorious Oersted; and in the darkest hours of misjudgment and despair it was he who supported me and promised me a better time. . . . One day when I had left him, sick in my soul from the injustice and hardness shown me by others, he could not rest before he, the older man, had looked me up at my house, late at night too, and there once more expressed his sympathy and consolation. It affected me so deeply that I forgot all my sorrow and pain and wept my fill in gratitude and bliss over his infinite goodness; I won again strength and courage to write and work. . . . his wealth of knowledge, experience, and genius, his charming naiveté, something innocent, unconscious as in a child, a rare character with the stamp of divinity were here revealed. . . . He was so mild and good. A child at heart and yet a deep philosopher.

Oersted worked happily to the very end. In March, 1851, he died, after less than a week's illness. He was mourned by his family, by his friends, and by the Danish people.

The Oersted medal of the American Association of Physics Teachers. In 1937 it was awarded to the late Professor Edwin H. Hall and in 1938, to Professor A. Wilmer Duff. A blank of the medal has been sent to Denmark for deposit in a collection commemorating Oersted's work. Professor Frederic Palmer, Jr. suggested the motif appearing on one face of the medal; namely, Oersted, scientist and teacher, discovering electromagnetism in the presence of his assembled pupils. The scene depicted is based on information obtained for the Committee on Awards by Professor J. Rud Nielsen, formerly of Copenhagen, and Professor F. K. Richtmyer, and is believed to be highly authentic. The design of the medal was carried out by the firm of Dieges and Clust.